

## CAMERA, IMAGING SYSTEM AND ILLUMINATION SENSOR

This application is a continuation-in-part of U.S. Application No. 09/319,920, which was the National Stage  
5 of International Application No. PCT/JP96/03683, filed December 17, 1996. The international application was published in Japanese under PCT Article 21(2).

### Technical Field of the Invention

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The present invention relates to a camera, an imaging system and an illumination sensor which are capable of correcting colors of a captured image of an object to correctly display the colors of the image.

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### Description of Related Art

Colors of objects are susceptible to illumination conditions, and it is therefore difficult to always  
20 display correct colors of images captured by a camera. Human eyes can correctly recognize actual colors of objects regardless of such conditions, which ability is known as color constancy.

Existing video cameras do not comprise imaging  
25 devices having this feature. Attempts are being made to implement the color constancy in imaging systems having

such video cameras by performing complicated correction,  
e.g., by comparing color of a particular point with the  
surrounding color to make correction. However, these  
attempts are not practical, since they are limited to  
5 correction to special images or the image processing  
takes a long time.

An object of the present invention is to provide an  
imaging system with good response which can correct  
colors of taken images of objects at practical speed to  
10 correctly display the colors of the images.

#### Summary of the Invention

15 A camera of the present invention comprising an  
imaging device for taking a color image and a lens for  
forming an image of an object on said imaging device,  
the imaging system comprising a reflection surface  
provided within a maximum field of view ( $V_m$ ,  $V_m$ ) formed  
20 by said lens and said imaging device, for diffuse-  
reflecting the image of said object to cause the image  
to impinge upon said imaging device through said lens,  
said imaging device having a direct image section for  
forming a direct image imaged as an object point on said  
25 object and an indirect image section for forming an  
indirect image of said object point obtained from said

reflection surface.

The analysis by the inventor described later,  
revealed that a diffuse-reflected indirect image at the  
reflection surface provided within the maximum field of  
5 view, represents the brightness at the object point.

Particularly, setting said reflection surface so  
that a direct image section for forming said direct image  
in said imaging device has a larger width than an  
indirect image section for forming said indirect image  
10 enables effective use of the maximum field of view of the  
imaging device. Moreover, as will be described later, it  
was confirmed that the color correction encounters no  
problem even when the width of the indirect image section  
is about 25% of the maximum field of view.

15 It is preferred that the imaging system comprises a  
cover provided on the side on which light comes into said  
lens, for intercepting light from outside of said maximum  
field of view at least. While light outside the maximum  
field of view causes errors in color correction, the  
20 cover reduces the errors.

The preferable way of correcting the color of the  
image is comparing the direct image and the indirect  
image.

It is preferable that the white balance of the direct  
25 image were performed by using colors on the indirect  
image.

When designing the reflection surface, the direct image and the indirect image of said object may be similar figures with respect to the direction in which said direct image section and said indirect image section are arranged. In this case, it is possible to corrected color small objects like flowers more precisely to the details.

The reflection surface may be so designed that the ratio of the numbers of corresponding pixels between the indirect image section for forming said indirect image and the direct image section for forming said direct image in the direction in which said direct image section and said indirect image section are arranged is constant. In this case, the algorithm for color correction can be simplified and the color correction can be achieved at very high speed.

The reflection surface can be shaped according to the following equation:

$$X_{ni} = f (A - \tan(2\alpha)) / (1 + A \cdot \tan(2\alpha))$$

Where  $f$  represents focal length of the lens,  $A$  represents  $(X/Z)$ ,  $X$  represents horizontal-direction distance of the object point  $P$  from a horizontal-reference line  $Ch$ ,  $Z$  represents vertical distance of the object point  $P$  from a vertical-reference line  $Cv$ , and  $\alpha$  represents an angle formed between the reflection surface and a horizontal line parallel to the vertical-reference

line Cv.

Experiments made by the inventor showed that forming said reflection surface with leather having oil or clear resin coating on its surface allows the color  
5 correction to be achieved very well.

An imaging system of the invention is further comprising a video capture digitizing the image sequentially scanned along the scan lines n said camera and stores the data into a memory, the image having said  
10 direct image section and said indirect image section .

It is preferable that the images were processed by dividing the colors on the direct image by colors on the indirect image in each color and the results by said dividing were multiplied with a common correction term  
15 (S) in three colors.

This imaging system of this invention, preferably, further comprising assigning device (means) for assigning each main coordinates (Xmi, Ymi) in said direct image obtained as an object point on said object is imaged on  
20 said imaging device to corresponding sub-coordinates (Xni, Yni) in said indirect image of said object point (P) obtained from said reflection surface on said imaging device, and a color-correcting device (portion) for obtaining an image color-corrected on the basis of the  
25 following expressions:

$$D1 (Xmi, Ymi) = (Rmi/Rni) \cdot S,$$

$$D2 (X_{mi}, Y_{mi}) = (G_{mi}/G_{ni}) \cdot S, \text{ and}$$

$$D3 (X_{mi}, Y_{mi}) = (B_{mi}/B_{ni}) \cdot S.$$

Where D1, D2, and D3 respectively represent R, G, B  
5 components of the corrected color image at said main  
coordinates (X<sub>mi</sub>, Y<sub>mi</sub>), R<sub>mi</sub>, G<sub>mi</sub>, and B<sub>mi</sub> respectively  
represent R, G, B components in a direct image pixel (P<sub>m</sub>)  
at said main coordinates (X<sub>mi</sub>, Y<sub>mi</sub>), R<sub>ni</sub>, G<sub>ni</sub>, and B<sub>ni</sub>  
respectively represent R, G, B components in an indirect  
10 image pixel (P<sub>n</sub>) at said sub-coordinates (X<sub>ni</sub>, Y<sub>ni</sub>), and  
S represents a correction term.

The analysis by the inventor described later,  
revealed that a diffuse-reflected indirect image at the  
reflection surface provided within the maximum field of  
15 view, represents the brightness at the object point.  
Accordingly, dividing R<sub>mi</sub>, G<sub>mi</sub>, and B<sub>mi</sub> respectively by  
R<sub>ni</sub>, G<sub>ni</sub>, and B<sub>ni</sub> representing the brightness eliminates  
errors due to effects of illumination. This was  
confirmed by experiments carried out by the inventor.  
20 The correction term S prevents the output resulting from  
the division of R<sub>mi</sub>, G<sub>mi</sub>, B<sub>mi</sub> by R<sub>ni</sub>, G<sub>ni</sub>, B<sub>ni</sub> from  
exceeding the limit of device scale width and becoming  
saturated.

An illumination sensor of the invention further  
25 comprising an imaging device for taking a color image and  
a lens for collecting the illumination, the illumination

color sensor comprising a reflection surface provided within a maximum field of view ( $V_m$ ,  $V_m$ ) formed by said lens and said imaging device , for diffuse-reflecting the image of said object to cause the image to impinge upon  
5 said imaging device through said lens , sensing the illumination color from the indirect image of said object point obtained from said reflection surface on said imaging device.

The present invention can be implemented by  
10 installing software for realizing the assigning device stored in a storage medium into a common personal computer and attaching the cover having the reflection surface to a common video camera.

As stated above, the features of the present  
15 invention provides an imaging system with good response which can correct colors of a taken image of an object at practical speed by comparing an indirect image from the reflection surface and a direct image so as to correctly display the colors of the object.

20 The present invention will become more apparent from the following detailed description of the embodiments and examples of the present invention. The reference characters in claims are attached just for convenience to clearly show correspondence with the  
25 drawings, which are not intended to limit the present invention to the configurations shown in the accompanying

drawings.

### Description of the Drawings

5            Fig.1 is an explanation diagram showing the relation among an object Ob, reflection surface, lens, and CCD device for explaining the principle of the present invention;

            Fig. 2(a) is a diagram showing the first  
10 convolution on the reflection surface due to diffuse reflection pattern, and Fig. 2(b) is a diagram showing the second convolution on the CCD device due to defocusing on the indirect image section Fn;

            Fig.3 shows the relation between a direct image Im  
15 and an indirect image In on the total image plane F; Fig. 3(a) in a nonlinear mapping, Fig.3 (b) in a linear mapping, and Fig. 3(c) with spot light illumination;

            Fig.4 shows assignment between direct image pixel groups Pm and indirect image pixels Pn; Fig. 4(a) in the  
20 nonlinear mapping, and Fig. 4(b) in the linear mapping.

            Fig.5(a) is a graph showing the relation between varying horizontal location of the object point P and the optimum reflection surface angle  $\alpha$ , and Fig. 5(b) is a graph showing the relation between the depth of the  
25 object point P and the viewing error angle  $\psi$ ;

            Fig.6(a) is a graph showing changes before and



after color correction in the relation between the illumination intensity and brightness, and Fig. 6(b) is a graph showing changes before and after color correction in the relation between the illumination intensity and x-chromaticity coordinate;

Fig.7(a) is a perspective view of a camera fitted with a guard cover, and Fig. 7(b) is a transverse sectional view showing the guard cover;

Fig.8 is a logical block diagram showing an imaging system according to the present invention;

Fig.9 is a diagram showing another embodiment of the present invention, which corresponds to Fig.1; and

Fig.10 is a block diagram of another embodiment of the invention, which comprise not only a camera but also an illumination sensor.

#### Detailed Description of the Invention

First, the principle of the present invention will be described referring to Figs.1 to 5.

The example of Fig.1 shows a simplified geometric model of optical paths. Now we consider the positional relation between an object point P on a general object Ob and a reflection reference point N, or a particular point on a reflection surface (nose surface) 18. The object point P on the object Ob is focused as a direct image on

a direct image section  $F_m$  of a CCD device 23 through "O" in the lens 21 of the camera 20. The image of the object point P on the object Ob is also diffuse-reflected at the reflection surface 18 of the reflector 15 and passes  
5 through the lens 21 to impinge upon an indirect image portion  $F_n$  of the CCD device 23 to form an indirect image. While the indirect image section  $F_n$  is not focused because the diffuse reflection at the reflection surface 18 and the reflection surface 18 are out of the focus of  
10 the lens 21, it is assumed here for simplicity that the reflection surface 18 causes mirror reflection, and the centers of the optical paths are shown as segments PN and NO for convenience.

The range surrounded by a pair of maximum field  
15 lines (planes)  $V_m$ ,  $V_m$  on the total image plane F of the CCD device 23 is the range in which the lens 21 can form an image on the CCD device 23, which corresponds to the maximum field of view. Needless to say, the maximum field of view extends in the direction perpendicular to  
20 the paper of Fig.1. In the total image plane F corresponding to this range, the regional indirect image section  $F_n$  surrounded by the maximum field line  $V_m$  extending from upper left to lower right and the boundary field line  $V_n$  connecting the reflection surface top 18a  
25 of the reflection surface 18 and the "O" in the lens 21 is the range in which the indirect image is formed. The

remaining regional direct image section  $F_m$  is the range in which the direct image is formed.

The horizontal-reference line  $Ch$  in Fig.1 is a reference axis passing through the center of the lens 21 to show the zero point with respect to the horizontal direction and the direction of the thickness of the paper, and the vertical-reference line  $C_v$  passing through the imaging plane of the CCD device 23 is a reference axis showing the reference point with respect to the vertical direction. The image coordinates are represented by  $(X, Y, Z)$  system coordinates. The characters  $X$ ,  $X_n$ ,  $X_{mi}$ , and  $X_{ni}$  in the drawing show the horizontal distances between the horizontal-reference line  $Ch$  and the object point  $P$ , reflection reference point  $N$ , direct image  $Im$  of the object point  $P$  on the direct image section  $F_m$ , and indirect image  $In$  of the object point  $P$  on the indirect image section  $F_n$ , respectively. Similarly, the horizontal distances between these points and the horizontal-reference line  $Ch$  in the direction perpendicular to the paper of Fig.1 are shown by the characters  $Y$ ,  $Y_n$ ,  $Y_{mi}$  and  $Y_{ni}$ . The characters  $Z$  and  $Z_n$  in the drawing indicate the vertical distances between the vertical-reference line  $C_v$  and the object point  $P$  and the reflection reference point  $N$ , respectively. In other words, the distance  $Z_n$  designates the depth of the reflection reference point  $N$ , and then the vertical

direction distance between the object point P and the reflection reference point N is given as  $Z-Z_n$ .

Light from an illuminant hits the surface of an object and is then reflected in a form dependent on the optical characteristics of the surface. The reflection seen by the camera 20,  $I(\lambda)$ , is given by the following expression.

$$I(\lambda) = E(\lambda) \cdot \rho(\lambda) \quad (1)$$

Where  $E(\lambda)$  is the spectral power distribution of the illumination,  $\rho(\lambda)$  is the surface reflectance of the object, and  $\lambda$  is the wave length. The reflection  $I(\lambda)$  is then decomposed into three colors R, G, and B. The reflection surface 18 reflects the illumination at a horizontally reduced resolution, as compared with that of the direct image  $I_m$ , and obtaining the indirect image  $I_n$  means a measure of the illumination in this way.

The specular-reflected ray at the reflection surface 18 is surrounded by a distribution of diffuse rays. It affects the ray reaching the indirect image section  $F_n$  on the CCD device 23 by different weights. For example, in Fig.2(a), the rays incident along the optical axes S1 and S2 have diffuse reflection intensity distributions approximated to the Gaussian distributions G1 and G2 having their respective peaks on the optical axes of specular reflections, S1 and S2. The ray on a

particular optical axis  $S_n$  toward the CCD device 23 affects, with values of intensity of DRC1 and DRC2, the rays reaching the CCD device 23 as the indirect image section  $F_n$ . With this approximation, the ray C reflected from a point on the nose can be expressed as follows:

$$C(X, Y) = \iint E_o(X, Y) \cdot \rho_o(X, Y) \cdot B_1(X, Y) dX dY \quad (2)$$

Where the letter "o" refers to a point on the object  $O_b$ . The ray C represents a weighted summation of all rays illuminating point N on the nose surface from the scenery points. The weighting factor changes with the changing angle of incidence and the roughness of the nose surface. The blurring factor  $B_1$  depends on the optical characteristics and roughness of the reflection surface 18.

As the reflection surface 18 is seen out of the focus of the lens 21, every ray reflected from the reflection surface 18 will be projected as a circle. The intensity distribution is approximated to vary according to Gaussian function across the diameter of the blur circle as shown in Fig.2(b). Thus every pixel in the indirect image section  $F_n$  of the CCD device 23 receives a weighted summation of a circular window. The size of this window depends on the blurring factor  $B_2$ , which in turn depends on the focal length and the depth of the reflection reference point N from the lens 21 of the

camera 20.

$$C_{ni} = \int \int B_2(X_{ni}, Y_{ni}) \cdot C(X_{ni}, Y_{ni}) dX_{ni} \cdot dY_{ni} \quad (3)$$

Where the letter  $n_i$  refers to pixel of the indirect  
5 image  $I_n$  and the sub-coordinates  $(X_{ni}, Y_{ni})$  refer to the  
coordinates of the indirect image on the CCD device 23.

Combining the two expressions containing the two  
kinds of blurring factors  $B_1$  and  $B_2$  results in two  
operations of spatial blurring. One is achieved on the  
10 reflection surface 18, and the other is achieved by  
defocusing on the CCD device 23 since the reflection  
surface 18 is imaged out of the focus of the lens 21.  
The blurring process is performed in two separately-  
controlled layers. We assume that the successive  
15 convolutions by combining the two expressions containing  
the two blurring factors represents the illumination  
color at the object point  $P$ . That is to say, we consider  
that the indirect image section  $F_n$  obtained on the CCD  
device 23 by reflection on the reflection surface 18,  
20 represents the illumination color at the object point  $P$   
or illumination in the vicinity thereof.

Accordingly, the color intensity signals  $D_1$ ,  $D_2$  and  
 $D_3$  obtained by calculation shown in the following  
expressions (4) represent corrected colors of the object  
25 point  $P$  on the object  $Ob$ . This is due to the fact that  
dividing  $R_{mi}$ ,  $G_{mi}$ ,  $B_{mi}$  at each main coordinate

representing the color at the object point P itself by  
R<sub>ni</sub>, G<sub>ni</sub>, B<sub>ni</sub> at the sub-coordinates representing the  
color at the object point P removes the effects of  
illumination color etc. at the object point P.

$$\begin{aligned} 5 \quad D1(X_{mi}, Y_{mi}) &= (R_{mi} / R_{ni}) \cdot S, \\ D2(X_{mi}, Y_{mi}) &= (G_{mi} / G_{ni}) \cdot S, \\ D3(X_{mi}, Y_{mi}) &= (B_{mi} / B_{ni}) \cdot S \\ (4) \end{aligned}$$

Where the letter m represents the direct image I<sub>m</sub>,  
10 n represents the indirect image I<sub>n</sub> from the reflection  
surface 18, and i represents an image on the CCD device  
23. The characters D1, D2 and D3 respectively represent  
R, G, and B components of the color-corrected image at  
the main coordinates (X<sub>mi</sub>, Y<sub>mi</sub>), R<sub>mi</sub>, G<sub>mi</sub>, B<sub>mi</sub>  
15 respectively represent R, G, B components in a direct  
image pixel (P<sub>m</sub>) at the main coordinates (X<sub>mi</sub>, Y<sub>mi</sub>), and  
R<sub>ni</sub>, G<sub>ni</sub>, B<sub>ni</sub> respectively represent R, G, B components  
in an indirect image pixel (P<sub>n</sub>) at the sub-coordinates  
(X<sub>ni</sub>, Y<sub>ni</sub>). The main coordinates (X<sub>mi</sub>, Y<sub>mi</sub>) stand for  
20 coordinates of the direct image obtained when the object  
point P is focused on the imaging device 23 and the sub-  
coordinates (X<sub>ni</sub>, Y<sub>ni</sub>) stand for coordinates of the  
indirect image of the object point P obtained by the  
reflection surface 18 on the imaging device 23. The  
25 factor S adjusts the absolute values so that the values  
D1 to D3 will not be saturated.

The role of the reflection surface 18 as a sensor for detecting spatial illumination can be confirmed by a simple experiment. When a strong spot light is directed to a white wall, the imaging system 1 of the invention  
5 takes the image shown in Fig.3(c). The direct image  $I_m$  of the spot appears as an image like a white circle on the left side of the boundary DL, and its indirect image  $I_n$  is projected at a reduced horizontal resolution as an ellipse with a surrounding flare. The reflection at the  
10 reflection surface 18 represents the illuminant color. The color of illumination can be changed by using color filters with an incandescent lamp. The narrow band light was projected on a white wall, and the R, G and B values were measured for corresponding patches in the direct  
15 image  $I_m$  and the indirect image  $I_n$ . The ratios of the color intensity signals ( $D_1$ ,  $D_2$ ,  $D_3$ ) were almost constant when the color of illumination was varied.

Next, the positional relation between the reflection surface 18 and the camera 20 will be described.

20 The reflection surface 18 and a horizontal line parallel to the vertical-reference line  $C_v$  forms an angle  $\alpha$ . The reflected ray from the reflection surface 18 represented by the line NO and the horizontal line forms an angle  $\xi$ , and the line NO and the reflection surface 18  
25 forms an angle  $\beta$ . The line NO and a perpendicular line to the reflection surface 18 forms an angle  $\theta$ . Since the



line NO indicates specular reflection of the line PN indicating the incident light at the reflection surface 18, the line PN and a perpendicular line to the reflection surface 18 also forms the angle  $\theta$ . The character  $f$  denotes the focal length of the lens 21 of the camera 20. The angle formed between the line PN and a horizontal line is designated as  $x$ , the object point horizontal location angle between the line PO and a horizontal line as  $\phi$ , and the viewing error angle between the line PO and the line PN as  $\psi$ .

For the object point P,  $\psi = \phi - x$  (5).

For  $\angle PNO$ ,  $x + \xi = 2\theta$ .

For the vertically opposite angle about the reflection reference point N,  $\alpha = \xi + \beta$  holds.

From the relation about the perpendicular line to the reflection surface 18 around the reflection reference point N,  $\beta = \pi/2 - \theta$ .

From the above two expressions around the reflection reference point N,  $\xi = \alpha - \beta = \alpha + \theta - \pi/2$  holds, and further,  $\theta = \xi - \alpha + \pi/2$  holds.

When the expressions above are rearranged, the following equation holds:

$$\begin{aligned}\psi &= \phi - x = \phi - (2\theta - \xi) = \phi + \xi - 2\theta = \phi + \xi - 2(\xi - \alpha + \pi/2) \\ &= \phi + \xi - 2\xi + 2\alpha - \pi = \phi - \xi + 2\alpha - \pi\end{aligned}$$

(6)

The angle  $\alpha$  of the reflection surface 18 can be calculated using the equation above. The object point horizontal location angle  $\phi$  can be obtained using the equation below.

$$\phi = \tan^{-1}((Z - f) / x) \quad (7)$$

The angle  $\xi$  is an index indicating the horizontal direction coordinate of the reflection reference point N on the reflection surface 18 or the indirect image In, which can be obtained by

$$\xi = \tan^{-1}(f / X_{ni}) \quad (8)$$

The optimum angle  $\alpha$  of the reflection surface 18 with the changing horizontal coordinate of the object point P is shown in Fig.5(a). The angle  $\alpha$  was calculated by setting the viewing error angle  $\psi$  to a small value of 2 degrees. Other angles were represented by their average magnitudes. In Fig.5(a), the object point horizontal location angle  $\phi$  is shown on the abscissa and the angle  $\alpha$  of the reflection surface 18 is shown on the ordinate. It is preferred that the angle  $\alpha$  of the reflection surface 18 be appropriately decreased when the object point horizontal location angle  $\phi$  increases, so as to keep the viewing error angle  $\psi$  to a small and almost constant value.

As shown in Figs.1, 3 and 4, each image line

consists of the direct image section  $F_m$  for taking the direct image  $I_m$  and the indirect image section  $F_n$  separated by the boundary  $DL$  for taking the indirect image  $I_n$ . The boundary  $DL$  separating the direct image section  $F_m$  and the indirect image section  $F_n$  corresponds to the reflection surface top 18a of the reflection surface 18. Mapping in this invention is defined as assigning indirect image pixels  $P_n$  forming the indirect image section  $F_n$  to direct image pixel groups  $P_m$  in the direct image section  $F_m$ . Mapping becomes difficult when the object  $Ob$  is located near the camera 20, for the angle  $\psi$  is a measure of the viewing error. The angle  $\psi$  is required to be as small as possible to minimize the view difference between the direct image  $I_m$  and the indirect image  $I_n$ . When the angle  $\psi$  is large, the object  $Ob$  will be seen in the direct image section  $F_m$ , but not be visible in the indirect image section  $F_n$ , or vice versa. The angle  $\psi$  can be expressed in terms of coordinates of the reflection surface 18. Referring to the geometry of Fig.1, the following expression can be derived.

$$\tan(x) = (Z - Z_n) / (X_n - X)$$

(9)

Obtaining tangents on both sides in Eq.(5) provides the following equation.

$$\tan\psi = (\tan\phi - \tan(x)) / (1 + \tan\phi \cdot \tan(x))$$

(x)) (10)

From Eqs.(9) and (10) above, the following equation can be obtained.

$$\tan \psi = \frac{(X_n(Z-f) + Z_n \cdot X + X \cdot f - 2X \cdot Z)}{(X_n \cdot X + Z_n(f-Z) + Z(Z-f) - X^2)}$$

(11)

Eq.(11) represents the dependency of the angle on both of the object point P (X, Z) and the reflection reference point N (Xn, Zn) on the reflection surface 18. When X is set to be equal to zero in Eq.(11), the value of tangent angle at the camera optical axis points can be obtained as shown by Eq.(12) below.

$$\tan \psi = (X_n(Z-f) / (Z_n(f-Z) + Z(Z-f)))$$

(12)

An increase in the reference point horizontal distance Xn, or the horizontal distance between the reflection reference point N and the horizontal-reference line Ch, will result in a subsequent increase in the viewing error  $\psi$ . Therefore it is preferable to place the reflection surface 18 as horizontally close to the horizontal-reference line Ch as possible. The error angle  $\psi$  increases with an increase in the depth Zn of the reflection reference point N. Thus the depth Zn of the reflection reference point N from the lens 21 of the camera 20 should be as small as possible.

Fig.5(b) shows the dependence of the viewing error

angle on the object distance  $Z$ . An increase in the distance  $Z$  decreases the viewing error angle  $\psi$ . The error angle  $\psi$  will be at considerable values for objects Ob placed near, but it is less than 2 degrees at  
5 distances of 40 cm or longer. The viewing problem is not serious unless the lighting is made in stripes with fine resolution. For normal lighting conditions, the illuminance does not exhibit high frequency changes. The error angle  $\psi$  increases as the reference point horizontal  
10 distance  $X_n$  from the reflection reference point N increases. This effect is minimized if the angle  $\alpha$  of the reflection surface 18 changes according to the trend shown in Fig.5(a).

From Eqs.(5) and (6) above,  $x = \phi - \psi = \pi + \xi - 2\alpha$ ,  
15 and further, obtaining tangents of these equations provides the following equation.

$$\tan(x) = \tan(\pi + \xi - 2\alpha) = \tan(\xi - 2\alpha)$$

(13)

When Eqs.(7) and (8) are substituted in the  
20 equation above, the following equation is obtained.

$$\begin{aligned} & (Z - Z_n) / (X - X_n) \\ &= ((f - X_n i \cdot \tan(2\alpha)) / (X_n i + f \cdot \tan(2\alpha))) \end{aligned}$$

(14)

With  $(X/Z)=A$ , Eq.(14) above can be expanded and  
25 rearranged to present the following equation.

$$X_n i / f$$

$$= ((A - \tan(2\alpha)) - (X_n/Z - (Z_n/Z) \cdot \tan(2\alpha))) / ((1 + A \cdot \tan(2\alpha)) - ((X_n/Z) \cdot \tan(2\alpha) + Z_n/Z)) \quad (15)$$

Further, when  $Z \gg Z_n$ , and  $X \gg X_n$ , the latter terms  
 5 in the numerator and denominator are then equal to zero,  
 and the following equation holds.

$$X_{ni} = f(A - \tan(2\alpha)) / (1 + A \cdot \tan(2\alpha)) \quad (16)$$

This equation describes the mapping on the  
 10 horizontal coordinate between the direct image  $I_m$  and the  
 indirect image  $I_n$  of the object  $O_b$  in the same scan line  
 SL.  $X_{ni}$  designating the coordinate of a point on the  
 indirect image section  $F_n$  corresponding to one object  
 point  $P$  on the object  $O_b$  does not clearly depend on the  
 15 value of the distance, but rather depends on the ratio  
 $A = (X/Z)$ . This can be explained by considering the  
 omission of  $Z_n$  in the equation. When it is assumed that  
 the object  $O_b$  is sufficiently distant from the position  
 of the camera 20, then the angle  $\psi$  will be very small.  
 20 In this case, if the object point  $P$  moves along  $OP$ , the  
 reflection at the reflection surface 18 on the segment  $PN$   
 slightly changes. As shown by Eq.(16), the mapping is  
 directly related to the determination of the profile of  
 the reflection surface 18.

25 Figs.3(a) and 4(a) show a method of nonlinear  
 mapping, and Figs.3(b) and 4(b) show a method of linear

mapping. The mapping can be selected between the nonlinear and linear relations by defining  $X_{ni}$ ,  $A=(X/Z)$  and the angle  $\alpha$  of each small part of the reflection surface in Eq.(16) in the positional relation between the direct image section  $F_m$  and the indirect image section  $F_n$ . Fig.4 shows the correspondence between a direct image pixel group  $P_m$  on the direct image section  $F_m$  and an indirect image pixel  $P_n$  on the indirect image section  $F_n$  on one scan line  $SL$ , where the arrows show the direct image pixel groups  $P_m$  and the indirect image pixels  $P_n$  which correspond to each other when they are obliquely shifted. While the direction of mapping in the direct image section  $F_m$  is directed as shown by the arrow  $M_m$ , the mapping direction in the indirect image section  $F_n$  is directed as shown by the reversely-directed arrow  $M_n$ . Usually, the boundary  $DL$  between the direct image section  $F_m$  and the indirect image section  $F_n$  is perpendicular to the lower edge of the total image plane  $F$ .

In the nonlinear mapping shown in Figs.3(a) and 4(a), the indirect image pixels  $P_n$  are assigned to corresponding direct image pixel groups  $P_m$  composed of different numbers of pixels. In this mapping, the dimensions of the corresponding portions in the direct image  $I_m$  and the indirect image  $I_n$  are assigned so that  $a/d = b/c$ . That is to say, they are so assigned that the direct image  $I_m$  and the indirect image  $I_n$  of the object

Ob are similar figures with respect to the direction in which the direct image section  $F_m$  and the indirect image section  $F_n$  are arranged. This mapping is suitable for precisely color-correcting small parts in an image, e.g.,  
5 when taking pictures of small objects like flowers.

In the linear mapping shown in Figs.3(b) and 4(b), they are so assigned that the ratio of the numbers of corresponding pixels between the indirect image section  $F_n$  and the direct image section  $F_m$ ,  $(P_m/P_n)$ , is constant  
10 in the direction in which the direct image section  $F_m$  and the indirect image section  $F_n$  are arranged. In this mapping, the dimensions of corresponding parts in the direct image  $I_m$  and the indirect image  $I_n$  are so assigned that  $a/d$  and  $b/c$  are not uniform. That is to say, the  
15 direct image  $I_m$  and the indirect image  $I_n$  cannot be similar, and the parts in the direct image section  $F_m$  are color-corrected at uniform resolution. This mapping enables high speed image processing, which provides color-corrected image almost on a real-time basis. The  
20 assigning device for performing the assignment can be implemented by using a personal computer 30, as will be described later.

The entirety of the reflection surface 18 is not linear as shown in Fig.1, but individual small parts have  
25 different surface angles  $\alpha$ , the entirety of which is formed in a curved shape. The reflection surface 18 is



drawn in a linear shape in Fig.1 only for convenience in description.

When graphically designing the reflection surface 18, first, the angle  $\alpha$  of a small part on the reflection surface at the reflection surface top 18a is determined  
5 such that the visible image vertical extreme lines can be projected on the indirect image section  $F_n$  on the right side of the boundary DL on the CCD device. The angle  $\alpha$  of each small part on the reflection surface was  
10 determined on the basis of the requirement shown in Fig.5(a). The Length projected from a direct image and the corresponding length of small part on the reflection surface 18 were graphically measured at a depth of one meter. In this case, the difference in depth did not  
15 cause considerable errors as estimated numerically from Eq.(16). That is to say, it can be said that a mapping equation is fitted to the graphical measurements of pixels between the direct image section  $F_m$  and the indirect image section  $F_n$ .

20 When numerically designing the reflection surface 18, first, the coordinates of the reflection surface top 18a,  $(X_o, Z_o)$ , are obtained from the boundary of the light reaching the camera 20. When using the linear mapping, the above-described  $A = (X/Z)$  and  $M = (X_{ni}/f)$   
25 are obtained from the correspondence between the indirect image section  $F_n$  and the direct image section  $F_m$ , and the

angle  $\alpha$  of the small part of the reflection surface at that coordinates is determined by using Eq.(16). Next, by using the following equations (17) and (18), coordinates of a part separated from the coordinates  $(X_0, Z_0)$  by a small distance are obtained. The characters "n" and "n-1" in the following two equations indicate relation between an (n-1)th small part closer to the reflection surface top 18a, when the reflection surface 18 is divided into small parts, and an nth small part location on the side closer to the reflection surface end 18b away from the top. Further, the angle  $\alpha$  at the newly obtained coordinates  $(X_n, Z_n)$  is obtained from Eq.(16) above. This process is sequentially repeated to determine the curved plane of the reflection surface 18.

$$Z_n = (Z_{n-1} - \tan \alpha_{n-1} (M_n \cdot f_n - X_{n-1})) / (1 - M_n \cdot \tan(\alpha_{n-1}))$$

(17)

$$X_n = X_{n-1} + (Z_{n-1} - Z_n) \tan \alpha_{n-1}$$

(18)

Next, a structure of an imaging system according to the present invention will be described referring to Figs.1, 3, 4, 7 and 8.

Fig.7 shows a specific structure around the camera 20, where a guard cover 10 having a reflector 15 is attached to the front side of the camera 20. The guard cover 10 has a body 11 shaped in a prismoid and a fitting

part 12 to be fitted on the camera 20. The body 11 of the guard cover 10 prevents invasion of light into the camera 20 from outside of the range surrounded by the pair of maximum field lines (planes)  $V_m$ ,  $V_m$  shown in

5 Fig.1. Intercepting the light from outside of the range surrounded by the pair of maximum field lines  $V_m$ ,  $V_m$  is desired because it gives error to the light from the reflection surface 18 for correcting the image.

The reflector 15 is attached on one of the inner  
10 sides of the body 11, which comprises a base 16 for defining the surface shape of the reflection surface 18 and a skin 17 stuck on the surface of the base 16. The surface of the skin 17 on the reflection surface 18 side is matte and black- or gray-colored to diffuse-reflect  
15 light, on which oil is applied to form film.

Fig.8 is a logical block diagram showing the imaging system 1; the imaging system 1 includes, as main members, the guard cover 10, camera 20, personal computer 30, monitor device 41, and color printer 42. The image  
20 captured through the lens 21 of the camera 20 is formed on the CCD device 23 with its quantity of light adjusted through the diaphragm 22. The output from the CCD device 23 is captured into the video capture 31 in the personal computer 30 and is also given to the frame integrator 24,  
25 which obtains the quantity of light of the taken image to control the quantity of aperture of the diaphragm 22 with

the aperture motor 25 so that the output of the CCD device 23 will not be saturated.

The personal computer 30 is a common product, which is constructed by installing software in storage means like a hard disk, RAM, etc. to implement various functions of the timer 32, color application circuitry 37, etc. described later. This software can be distributed in a form stored in a storage medium such as a CD-ROM, flexible disk, etc. The video capture 31 digitizes the image sequentially scanned along the scan lines SL in the camera 20 and stores the data into a memory. The timer 32 functions as trigger for determining the position of the boundary DL for separating the direct image section  $F_m$  and the indirect image section  $F_n$  in the total image stored in the memory. In this embodiment, the direct image section  $F_m$  in the total image contains 240 pixels and the indirect image section  $F_n$  contains 80 pixels. The mapper 33 maps individual indirect image pixels  $P_n$  contained in the indirect image section  $F_n$ , 80 per one scan, to corresponding direct image pixel groups  $P_m$  in the direct image section  $F_m$ . This mapping is performed in a nonlinear or linear manner according to Eq.(16) as explained above.

The color corrector 34 obtains  $D_1$ ,  $D_2$ , and  $D_3$  according to Eq.(4) and the maximum selector 35 obtains the maximums value of these values in the full image.

The level at which the maximums value is not saturated corresponds to the appropriate value of the correction term  $S$  as the factor in Eq.(4), and the scaler 36 determines the appropriate value of the correction term  $S$  in the color corrector 34, and the values of the outputs  $D1$ ,  $D2$  and  $D3$  are corrected. For example, with a 8-bit computer, the scale width in information processing is 256 and a scale width of about 85 is assigned to each of  $R$ ,  $G$ ,  $B$ , and therefore the correction term  $S$  is set so that the maximum value of the scale width for  $D1$ ,  $D2$ , and  $D3$  is 85 or smaller. Larger scale widths can be assigned with 16- or 32-bit computers, so as to represent colors at finer tones.

The color application circuitry 37 serves as means for storing, reproducing, editing, etc. the color-corrected image, which is implemented by driving software stored in a hard disk or the like by a CPU or other hardware. The image reproduced by the color application circuitry 37 is displayed as color moving picture, for example, in the monitor device 41 through the video accelerator 38, and is also printed in colors as still picture through the I/O port 39 and the color printer 42.

To verify the invention, a SONY XC-711 (trademark) color video camera was used as the camera 20 and a 12.5 mm focal length COSMICAR C-mount lens (trademark) was used as the lens 21. The color parameters were measured

using a MINOLTA chroma meter module CS-100 (trademark). The prototype configuration of the imaging system 1 was used to obtain still images to obtain experimental data. While the skin 17 was made of gray matte paper to cause  
5 diffusion reflection, the use of leather having a coat of oil provided better results. The width ratio of the indirect image section  $F_n$  to the total image plane  $F$  was limited to a maximum of 25%. The processing time on the personal computer 30 using Pentium (trademark) with 120  
10 MHz operation clock was 0.55 second for a 320×220 pixel image.

The applicability of the imaging system 1 which corrects surface color can be confirmed by studying the effects of illumination intensity on color quality. The  
15 inventor carried out experiments with some pieces of full color images subject to combined daylight and fluorescent illumination. The images were processed by dividing the colors on the direct image  $I_m$  by colors on the indirect image  $I_n$ . The image colors were improved, and dark  
20 images got brighter with observable details while strong illumination pictures got darker. Dark images below 100 lx were noisy even after processed by the method using the reflection surface 18.

A separate experiment was carried out to detect the  
25 quantitative quality of color correction provided by this imaging system 1. A red color patch was set on a camera

plane and the color of the patch was compared at different illumination intensities. The effect of lighting intensity on the brightness of the red color patch before and after correction is shown in Fig.6(a).

5 The abscissa shows the illumination intensity and the ordinate shows the brightness of the red color patch. As shown in the curve "Before correction", an increase in scene illumination intensity usually results in an increase in brightness of the color patch in the image.

10 As shown in the curve "by After correction", the brightness of the patch after corrected is almost constant and stable even when the illumination intensity is changed. The effect of illumination intensity on the x- and y-chromaticity coordinates based on CIE 1931

15 standard is shown in Fig.6(b). As shown in the curve by Before correction in Fig.6(b), the x-chromaticity coordinate of the red color patch shown on the ordinate increases as the illumination intensity shown on the abscissa increases. This implies a hue distortion of the

20 original color at different lighting intensities. The x-chromaticity coordinate in the corrected images decreases slightly as the illumination intensity increases. While, as shown in Figs.6(a) and (b), the values of brightness and x-chromaticity coordinate at 100 lx corresponding to

25 the lowest illumination intensity are always different from those at larger intensity points, it is possible to

maintain the constancy of illuminance and hue at lower illumination intensities by changing the conditions for setting the reflection surface.

The correction to image colors by the imaging  
5 system 1 using the reflection surface 18 eliminated distorted original colors of images. The corrected color histograms of one image under different light intensities were all similar. This shows that the lighting intensity has no global effect. As shown in Figs.6(a) and (b), the  
10 color parameters before and after color correction show that the color brightness and hue vary only slightly when the illumination intensity varies in a certain range.

Then, other possible embodiments of the invention will be described.

15 Although the total image plane F in the CCD device 23 is plane-shaped in the above-described embodiment, it is logically possible to use a CCD device 23 having its total image plane F shaped in a curved surface around the point O in the lens 21, for example. In this case,  
20 Eq.(15) shown above can be replaced by the equation below.

$$\begin{aligned} & \tan(2\alpha) \\ &= (A \cdot \tan\xi + 1 - ((Z_n/Z) + (X_n/Z) \cdot \tan\xi)) \\ & \quad / (1 - A \cdot \tan\xi + ((Z_n/Z) \cdot \tan\xi - (X_n/Z))) \\ & (19) \end{aligned}$$

25 Further, when  $Z \gg Z_n$ , and  $X \gg X_n$ , the latter terms in the numerator and denominator in the equation above



are then equal to zero and the following equation for replacing Eq.(16) holds.

$$\begin{aligned} & \tan(2\alpha) \\ &= (A \cdot \tan\xi + 1) / (1 - A \cdot \tan\xi) \end{aligned}$$

5     (20)

The curved surface of the reflection surface 18 can be designed on the basis of this equation (20) in place of the equation (16) shown before.

Although the reflection surface 18 is made of black  
10 leather having oil coating thereon in the above-described embodiment, the reflection surface may be made of other material having matte gray surface, for example, as long as it causes diffuse reflection of light at appropriate intensity or be made of metal foil or layer like aluminum,  
15 and the surface may have varnished resin coating.

Although using the CCD device 22 for the imaging device in the above-described embodiment, it may be possible to use some kind of devices such as CMOS device for the imaging device.

20     In the embodiment above, in mapping, one indirect image pixel P<sub>n</sub> is assigned to a direct image pixel group P<sub>m</sub> composed of a plurality of direct image pixels to show a practical example. However, one indirect image pixel P<sub>n</sub> may be assigned to one direct image pixel P<sub>m</sub> when the  
25 indirect image section F<sub>n</sub> and the direct image section F<sub>m</sub> have equal width, and, it is also logically possible to

assign an indirect image pixel group  $P_n$  composed of a plurality of indirect image pixels to one direct image pixel  $P_m$  when the indirect image section  $F_n$  has larger width than the direct image section  $F_m$ .

5           The average value of an indirect image pixel group  $P_n$  can represents the illumination color of the main image scope, so the main image color or white balance color can be corrected by the average value without mapping. In this case, the area of the indirect image  
10   section  $F_n$  can be smaller than the above.

          Finally, yet another embodiment of the present invention will be explained while referring to Fig. 10. In this embodiment, in addition to the main camera 20', an illumination color sensor 50 is provided. The average  
15   value of the multiple pixels of the above-mentioned indirect image collected at CCD 22 via the reflection surface 18 and the lens 21 is computed with the processing section 60, and the illumination colors taken with the main camera 20' are determined with this sensor  
20   50. These illumination colors are output as OP1 for each separate RGB components. Meanwhile, the main image of the object is taken with the main camera 20' via the lens 21' and the CCD 22'. The output of this main image is connected to amplifiers 34a, 34b, and 34c provided for  
25   each respective color of the three colors RGB. Output RGBs of the procession section 60 are respectively

connected to each amplifier, white balance adjustment is performed referring the illumination colors. However, for the white balance adjustment, it is not always necessary to control all three colors; as shown in reference numerals 34a and 34b of the drawing, from among the three colors, if at least two colors are controlled, then such is sufficient. The same applies to the above-described software processing, too. However, it is desirous to perform control for all three colors in order to get maximum use of the dynamic range of the CCD. The corrected results of the main camera 20' are output from OP2. It is noted that the OP1 stated above may also be used for color determinations of other illumination colors.

15       The above-described imaging system (apparatus) can be applied to adjusting the white balance of a video cameras for taking moving pictures and digital cameras for taking still pictures, etc. The imaging system can also be preferably applied not only to stereo range finders on a color basis but also to the illumination color sensor. Current stereo range finders are designed to detect characteristic points on every scan line on the basis of change of color code. The characteristic points are compared between the right and left stereo images, and the correspondence is determined when the color codes are similar. Stabilization of the color codes is a major

advantage of the color constancy of the present invention,  
and application of this imaging system to the stereo  
range finders enhances the stereo matching reliability.

The disclosure of U.S. Patent Application No.  
5 09/319,920 filed on June 17, 1999 including specification,  
drawings and claims is incorporated herein by reference  
in its entirety.

Although only some exemplary embodiments of this  
invention have been described in detail above, those  
10 skilled in the art will readily appreciated that many  
modifications are possible in the exemplary embodiments  
without materially departing from the novel teachings and  
advantages of this invention. Accordingly, all such  
modifications are intended to be included within the  
15 scope of this invention.